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Supplementary Guidelines for Lead Implementation Plans Revised Section 4.3 (Projecting Automotive Lead Emissions)

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This guidance is a complete revision to Section 4.3 (Projecting Automotive Lead Emissions), in the "Supplementary Guidelines for Lead Implementation Plans," U.S. EPA, EPA-450/2-78-038, Research Triangle Park, North Carolina, August 1978. This revision changes the basic equation for projecting automotive lead emissions. It also clarifies the procedure for determining area source automotive emissions and provides updated information on automotive fuel economy and lead content of gasoline.

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INTRODUCTION

The following material is a complete revision to Section 4.3, Projecting Automotive Lead Emissions, in the "Supplementary Guidelines for Lead Implementation Plans," U.S.EPA, EPA-450/2-78-038, Research Triangle Park, North Carolina, August 1978.

This revision changes the basic equation for projecting automotive lead emissions presented in the original edition of the Supplementary Guidelines. In addition, new data on automotive fuel economy and lead content of gasoline are presented.

The procedure herein should be used to project automotive lead emissions instead of the procedure given in the original Supplementary Guidelines. The new procedure will generally result in higher projections of automotive lead emissions.

Those agencies developing State Implementation Plans for lead should also note the revision being made affects the EPA guideline, "Development of an Example Control Strategy for Lead" (EPA-450/2-79-002). Specifically affected are equations 2.3 (p. 14), 2.4 and 2.5 (p. 15) and the related discussion, which are based on the previous procedure. The new procedure should be used in lieu of that given on pp. 14 and 15 and related pages of the example control strategy for lead.

4.3 PROJECTING AUTOMOTIVE LEAD EMISSIONS

Lead emissions from mobile sources are calculated based on emissions at different speeds, the lead content of gasoline, vehicle fuel economy and the model year mix of vehicles on the road. The lead content of gasoline and the model year vehicle mix are a function of the calendar year of interest. Vehicle fuel economy is averaged for all vehicles of the same model year.

4.3.1 Lead Emissions from Automobiles

4.3.1.1 Individual Roadways--For any given year subsequent to 1974, the total population of automobiles on the road consists of vehicles using either leaded or "nonleaded" (i.e., 0.05 gram/gal.) gasoline. It is assumed that 95 percent of the model year automobiles from 1975 and beyond require the use of nonleaded gasoline. The emission rate from automotive sources from an individual roadway (line source) is calculated by the following equation:

$$e_{n,s} = \frac{a_s T}{C_t}\left[Pb_{NL,n}\sum_{i=1975}^{n}\left(\frac{m_{NL,i}}{C_{s,i}E_{c,i}}\right) + Pb_{L,n}\sum_{i=1967}^{n}\left(\frac{m_{L,i}}{C_{s,i}E_{c,i}}\right)\right] \quad (1)$$

where:

$e_{n,s}$ = emission rate for calendar year n and speed s (g/road mile-day);

a_s = percentage of lead burned that is exhausted; available from Figure 4.3-1 (nondimensional; expressed as a decimal); for roadway portions subject to full-throttle acceleration (0-60 mph) assume a_s=10.0;

T = average daily traffic (vehicles/day);

C_t = traffic flow correction factor; C_t=1.2297 for free-flow traffic; C_t=0.866 for city (stop-and-go) traffic (nondimensional);

$Pb_{NL,n}$ = lead content of "nonleaded" gasoline in calendar year n from Table 4.3-3 (g/gal);

$Pb_{L,n}$ = average lead content of leaded gasoline in calendar year n from Table 4.3-3 (g/gal);

$m_{NL,i}$ = fraction of annual travel by model year i vehicles using nonleaded gasoline (nondimensional, expressed as a decimal);

$m_{L,i}$ = fraction of annual travel by model year i vehicles using leaded gasoline (nondimensional, expressed as a decimal);

$C_{s,i}$ = speed-dependent fuel economy correction factor for model year i; calculation is described below in equation (2) (nondimensional);

$E_{c,i}$ = city/highway combined fuel economy for model year i from Table 4.3-5 (vehicle-road mile/gal).

To calculate the emission rate in units of grams/meter-second, $e_{n,s}$ can be corrected by dividing by 1.39×10^8.

$C_{s,i}$, the nondimensional speed dependent fuel economy correction factor for model year i, is calculated by the following equation:

$$C_{s,i} = \sum_{j=0}^{4} A_j S^j \qquad (2)$$

where:

A = correction factor from Table 4.3-1.

S = vehicle speed (miles/hour) [Note: $S^0=1$].

To simplify the computation, the values of $C_{s,i}$ for the years 1967 to 1985 are reproduced in Table 4.3-2.

4.3.1.2 Area Source Automotive Emissions--Equation (1) may be used to calculate automotive emissions as an area source rather than as specific line sources; however, certain computational modifications will need to be made. The term "T" should be replaced by the term "V," the vehicle miles travelled in the area on a daily, monthly or greater time basis. When VMT data are used, the emission rate, $e_{n,s}$, will be expressed in grams per day, month, etc. Also, when the VMT data indicate a balance of free-flow and city-type driving, the traffic flow correction factor, C_t, can be assumed equal to unity ($C_t = 1$) since fuel economies are representative of combined city/highway driving. Where the VMT data indicate primarily free-flow or city-type driving, correction factors of 1.2297 or 0.866, respectively, should be used as is the case with line source estimates.

The computation of area emissions precludes the use of Figure 4.3-1 for determining the percentage of burned lead exhausted, a_s. Figure 4.3-1 is based primarily on tests of lead emissions from vehicles operating at steady speeds over short test periods. An emission factor of 0.70 (i.e., 70 percent of the lead burned is exhausted) should be assumed when calculating automotive emissions as an area source rather than as specific line sources. The 0.70 factor is based on tests which measured exhaust emissions under city-type driving conditions.

Finally, the determination of the speed dependent fuel economy correction factor, $C_{s,i}$, should be based on the average vehicle speed for the area of concern. The average area vehicle speed should be a weighted average based on average speeds and VMT data for the various roadway classifications, such as limited access (greater than 50 mph), suburban roads (35 mph) and urban streets (25 mph or less).

4.3.2 Lead Emissions from Other Gasoline Powered Vehicles

Motorcycles and diesel-powered vehicles are assumed to emit quantities of lead that are insignificant compared to other gasoline-powered vehicles.

There are no known measurements of lead emissions from either light- or heavy-duty trucks. Therefore, for purposes of calculating emissions, the percentage of lead burned that is exhausted from these vehicles at various speeds is assumed to be the same as that for automobiles (Figure 4.3-1).

Light-duty gasoline-powered trucks are assumed to have the same gasoline economy as automobiles; new light-duty trucks (model year 1979 and beyond) are assumed to require the use of non-leaded gasoline to meet emissions standards for CO and hydrocarbons through the use of catalysts. Therefore, the emission rate for light-duty gasoline-powered trucks is calculated using the same procedures and parameters as for automobiles (except, of course, that the starting point for calculating emissions from nonleaded vehicles is 1979 rather than 1975).

Heavy-duty gasoline-powered trucks are assumed to burn leaded gasoline for all future years. Also, their fuel economy for any calendar year is assumed to be equal to 5.7 miles/gal. Therefore, the emission rate for heavy-duty gasoline-powered trucks is calculated by using the following modification of equation (1):

$$e_{n,s} = \frac{a_s TPb_{L,n}}{5.7}$$

where:

$e_{n,s}$ = emission rate for calendar year n (gram/road mile-day);

a_s = percentage of lead burned that is exhausted (non-dimensional; expressed as a decimal);

T = average daily traffic (trucks/day);

$Pb_{L,n}$ = average lead content of leaded gasoline in calendar year n from Table 4.3-3.

4.3.3 Example Calculation of Automobile Lead Emissions

Problem: For a city street with a speed of 16 miles per hour and average daily traffic of 28,000 vehicles, calculate the lead emission rate for the year 1983.

Solution: Use Equation (1):

$$e_{83,16} = \frac{a_{16}T}{C_t}\left[Pb_{NL,83}\sum_{i=1975}^{1983}\left(\frac{m_{NL,i}}{C_{16,i}E_{c,i}}\right) + Pb_{L,83}\sum_{i=1967}^{1983}\left(\frac{m_{L,i}}{C_{16,i}E_{c,i}}\right)\right]$$

From Figure 4.3-1, for a cruise speed of 16 mph, approximately 12.25 percent of the lead being burned is emitted. Therefore, $a_{16} = 0.123$.

The average daily traffic, T, is given as 28,000 vehicles/day. Since the roadway is a city street, the traffic flow correction factor C_t=0.866.

From Table 4.3-3, the lead content of leaded gasoline in 1983 is 1.5 grams/gal., and the lead content of nonleaded gasoline is 0.05 gram/gal.

The summations, $\sum_{i=1975}^{1983} \left(\frac{m_{NL,i}}{C_{16,i}E_{c,i}}\right)$ and $\sum_{i=1967}^{1983} \left(\frac{m_{L,i}}{C_{16,i}E_{c,i}}\right)$,

for vehicles burning nonleaded and leaded gasoline, respectively, must now be calculated. First, the fraction of annual travel, m_i, for each model year is determined by setting the fraction for 1 year old vehicles (Table 4.3-4) at the calendar year, n, for which lead emissions are being estimated. For this example, n=1983, therefore, m_{1983}=0.106 (vehicle age=1). [NOTE: The term, m_i, accounts collectively for all vehicles--leaded and nonleaded--in a given model year (i.e., $m_i = m_{NL,i} + m_{L,i}$). The calculation of this term is presented in Table 4.3-4, and its use is illustrated in Table 4.3-6.]

Next, it is necessary to calculate $C_{16,i}$, the speed-dependent fuel economy correction factor for model years 1967 through 1983, using Equation (2):

$$C_{16,i} = \sum_{j=0}^{4} A_j(16)^j$$

$$= A_0 + A_1(16) + A_2(16)^2 + A_3(16)^3 + A_4(16)^4$$

The A_j coefficients appear in Table 4.3-1 for each model year. Table 4.3-6 presents the results of that calculation for this example. Table 4.3-6 also presents the appropriate values for m_i from Table 4.3-4, and $E_{c,i}$ from Table 4.3-5.

Finally, by applying the assumption that 95 percent of the model year vehicles from 1975 and beyond use nonleaded gasoline (i.e., $m_{NL,i}=0.95\ m_i$), the summations for nonleaded and leaded gasoline can be completed as shown in Table 4.3-6. As that table indicates:

$$\sum_{i=1975}^{1983} \left(\frac{m_{NL,i}}{C_{16,i}E_{c,i}}\right) = 0.0552/\text{vehicle-road miles/gal.}$$

and,

$$\sum_{i=1967}^{1974} \left(\frac{m_{L,i}}{C_{16,i}E_{c,i}}\right) = 0.0127/\text{vehicle-road miles/gal.}$$

Substituting the above results into Equation (1), we obtain:

$$e_{83,16} = \frac{0.123 \times 28 \times 10^3 \text{ vehicles/day}}{0.866}\left[\frac{0.05\text{g/gal} \times 0.0552}{\text{veh-road mile/gal}} + \frac{1.5\text{g/gal} \times 0.0127}{\text{veh-road mile/gal}}\right]$$

$$= 86.74 \text{ g/road-mile-day}$$

In units of g/m-sec, this becomes:

$$e_{83,16} = \frac{86.74}{1.39 \times 10^8} = 6.24 \times 10^{-7} \text{ g/m-sec.}$$

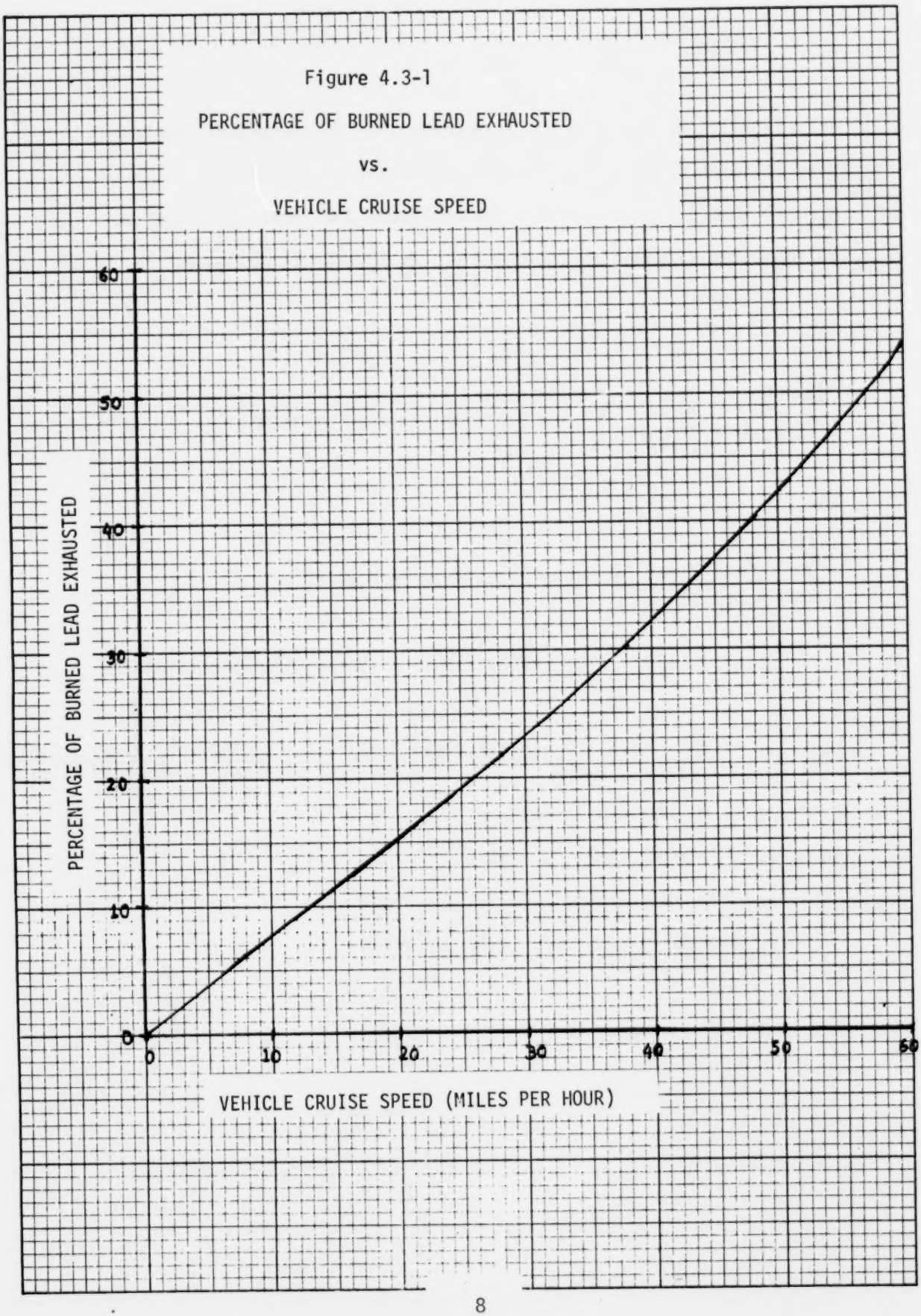
Figure 4.3-1
PERCENTAGE OF BURNED LEAD EXHAUSTED
vs.
VEHICLE CRUISE SPEED
PERCENTAGE OF BURNED LEAD EXHAUSTED
60
50
40
30
20
10
0
0
10
20
30
40
50
60
VEHICLE CRUISE SPEED (MILES PER HOUR)

TABLE 4.3-1

FUEL ECONOMY CORRECTION FACTORS BY MODEL YEAR

(NORMALIZED TO 32.7 MILES/HOUR)

Model Year	A_0	A_1	A_2	A_3	A_4
Pre-controlled	2.4697E-2	7.55258E-2	-2.42452E-3	4.01469E-5	-2.68893E-7
1968	1.75941E-2	6.90954E-2	-2.01359E-3	3.19426E-5	-2.12343E-7
1969	3.43032E-3	7.24956E-2	-2.18976E-3	3.54015E-5	-2.36485E-7
1970	6.00124E-3	6.90443E-2	-1.98463E-3	3.13931E-5	-2.09286E-7
1971	9.76255E-3	6.84494E-2	-1.96781E-3	3.13719E-5	-2.11167E-7
1972	8.57745E-2	7.0882E-2	-2.15219E-3	3.57324E-5	-2.44316E-7
1973-74	6.29988E-2	5.96559E-2	-1.59874E-3	2.59441E-5	-1.84877E-7
1975-85	4.01016E-2	7.50056E-2	-2.44301E-3	4.12554E-5	-2.82512E-7

Fuel Economy Correction Factor = $A_0 + A_1S + A_2S^2 + A_3S^3 + A_4S^4$

where S = vehicle speed in miles per hour

TABLE 4.3-2

$C_{s,i}$ VALUES

MODEL YEAR:	1967	1968	1969	1970	1971	1972	1973/4	1975-85
SPEED (MPH)								
5	.347	.317	.315	.305	.307	.391	.324	.359
10	.575	.537	.542	.527	.527	.613	.524	.584
15	.734	.698	.706	.690	.689	.773	.676	.740
20	.844	.816	.823	.811	.809	.889	.795	.843
25	.920	.903	.908	.900	.899	.976	.888	.923
30	.975	.963	.972	.969	.968	1.042	.965	.977
35	1.016	1.020	1.021	1.023	1.023	1.098	1.027	1.018
40	1.048	1.060	1.060	1.066	1.066	1.139	1.078	1.049
45	1.069	1.089	1.088	1.097	1.098	1.172	1.116	1.069
50	1.077	1.104	1.101	1.113	1.114	1.189	1.136	1.074
55	1.063	1.098	1.093	1.108	1.109	1.183	1.133	1.054
60	1.015	1.062	1.052	1.073	1.072	1.143	1.095	0.995

TABLE 4.3-3

LEAD CONTENT OF GASOLINE

Year	Leaded Gasoline* (g/gal)	Nonleaded Gasoline (g/gal)
1974	1.75	-
1975	1.9	0.05
1976	2.0	0.05
1977	1.9	0.05
1978	1.9	0.05
1979	2.1	0.05
1980	1.6	0.05
1981	1.2	0.05
1982	1.3	0.05
1983	1.5	0.05
1984	1.8	0.05
1985	2.2	0.05
1986	2.8	0.05
1987	3.0	0.05
1988	3.0	0.05
1989	3.0	0.05
1990	3.0	0.05

* 1974 - 1978: Lead content based upon historical sales data for leaded and nonleaded gasoline and data indicating the actual pooled average lead content.

1979 - 1990: Lead content based upon sales projections for leaded and nonleaded gasoline and requirements for pooled average lead content.

Table 4.3-4

TRAVEL WEIGHTING FACTOR CALCULATION*

Light-Duty Vehicles

Vehicle Age	(a) Fraction Total Registration	(b) Annual Mileage Accumulation Rate	(a)(b)	[(a)(b)/(SUM] Fraction of Annual LDV Travel by Model Year, m_i
1	0.075	15900	1192.5	0.106
2	0.107	15000	1605.0	0.142
3	0.107	14000	1498.0	0.133
4	0.106	13100	1388.6	0.123
5	0.100	12200	1220.0	0.108
6	0.092	11300	1039.6	0.092
7	0.085	10300	875.5	0.077
8	0.077	9400	723.8	0.064
9	0.066	8500	561.0	0.050
10	0.052	7600	395.2	0.035
11	0.039	6700	261.3	0.023
12	0.027	6600	178.2	0.016
13	0.018	6200	111.6	0.010
14	0.014	5900	82.6	0.007
15	0.009	5500	49.5	0.004
16	0.006	5100	30.6	0.003
17	0.005	5000	25.0	0.002
18	0.005	4700	23.5	0.002
19	0.005	4400	22.0	0.002
20	0.004	4400	17.6	0.002
		SUM:	11301.0	

*Mobile Source Emission Factors, March 1978 [EPA-400/9-78-005]

Table 4.3-5

CITY/HIGHWAY COMBINED FUEL ECONOMY

(miles/gallon)

Model Year	Fuel Economy $E_{c,i}$
1967	16.2
1968	15.6
1969	15.5
1970	15.4
1971	15.2
1972	15.2
1973	14.9
1974	15.2
1975	14.5*
1976	17.0*
1977	17.5*
1978	18.0**
1979	19.0**
1980	20.0**
1981	22.0**
1982	24.0**
1983	26.0**
1984	27.0**
1985	27.5**

* From U.S. DOT Report, "Automotive Fuel Economy Program" (44 FR, 5748, January 29, 1979)

** From U.S. DOT Report, "Automotive Fuel Economy Program" (44 FR, 5762, January 29, 1979)

TABLE 4.3-6

EXAMPLE CALCULATIONS

MODEL YEAR	AGE	m_i	$C_{16,i}$	$E_{c,i}$	$\frac{m_{NL,i}}{C_{16,i}E_{c,i}}$ *	$\frac{m_{L,i}}{C_{16,i}E_{c,i}}$
1983	1	.106	.765	26.0	.0050	.0003
1982	2	.142	.765	24.0	.0073	.0004
1981	3	.133	.765	22.0	.0075	.0004
1980	4	.123	.765	20.0	.0076	.0004
1979	5	.108	.765	19.0	.0070	.0004
1978	6	.092	.765	18.0	.0064	.0003
1977	7	.077	.765	17.5	.0055	.0003
1976	8	.064	.765	17.0	.0047	.0002
1975	9	.050	.765	14.9	.0042	.0002
1974	10	.035	.702	15.2	-	.0034
1973	11	.023	.702	14.9	-	.0022
1972	12	.016	.799	15.2	-	.0013
1971	13	.010	.716	15.2	-	.0009
1970	14	.007	.718	15.4	-	.0006
1969	15	.004	.732	15.5	-	.0004
1968	16	.003	.725	15.6	-	.0003
pre-1968	17+	.008	.759	16.2	-	.0007
					.0552	.0127

* $m_{NL,i} = 0.95m_i$

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